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# Optimized Link Distribution Schemes for Ultra Reliable and Low Latent Communications in Multi-layer Airborne Networks

Dong Wang, Shahriar Abdullah Al-Ahmed, Muhammad Zeeshan Shakir

**Abstract**—Ultra reliable and low latency communications (uRLLC) is one of the most significant requirements for future wireless networks. The conventional terrestrial base stations cannot always provide the required uRLLC for emerging applications and scenarios, e.g., Tactile Internet services or when a large number of users get connected during an event. Therefore, multi-layer airborne networks with low/medium/high altitude platforms can be deployed as an effective solution to offer capacity and coverage along with required latency and reliability for wireless networks. In this article, we propose a three layers airborne network to support the uRLLC requirement in wireless networks. Optimized link selection schemes have been provided based on Polychromatic Sets (PSets) theory to focus on the uRLLC. With the optimized link selection algorithm, multiple properties of the airborne platforms are exploited and the links are selected based on the multi-constrained requirements to support the desired performance of the airborne network. Moreover, two links distribution schemes have been proposed as distributed greedy scheme and centralized greedy scheme to demonstrate the deployment of proposed airborne network. Numerical results show that both PSets-based links distribution schemes outperform the general distribution schemes on average latency and overall reliability also known as unassociated ratio, which strongly supports the uRLLC in considered airborne networks.

**Index Terms**—Airborne networks, uRLLC, Polychromatic Sets theory, link distribution, latency, reliability.

## I. INTRODUCTION

The exponential growth of human-centric communication services (e.g., smart-phones and their complex applications) as well as machine based services (e.g., autonomous vehicles) causing many challenges to the wireless communication system with regard to capacity, latency, reliability, scalability and energy efficiency [1]. To face the puzzling challenges of diverse and complicated environment, International Telecommunication Union (ITU) has defined three major services for 5G wireless communication system, namely: enhanced mobile broadband (eMBB), massive machine type communication (mMTC) and ultra reliable and low latency communication (uRLLC) [2].

### A. Background

uRLLC is a new and challenging requirement among the three categories which has two conflicting specifications, namely, super low latency and ultra high reliability. One of

the typical example of uRLLC application is Tactile Internet services which has been developed rapidly in recent years [3]. Tactile Internet service is a human-machine collaboration that enables people to control the objects remotely in real time [3]. Many applications have been proposed in the Tactile Internet services, such as immersive virtual reality, Internet of flying platforms, industry automation, tele-surgery, etc. [3] and [4]. uRLLC is considered as an extremely crucial for these type of applications. Similarly, uRLLC is equally important for networks which are deployed during unexpected scenarios, such as in emergency situations to support disaster relief activities. The typical requirement of uRLLC is that the latency should be lower than 10ms and the reliability should be better than 99.999% [4] and [5]. As a result, there are challenges in link layer, network layer and physical layer [1]. For example, if we look at the physical layer, reducing the end-to-end latency mandates the use of short packets which affects the channel coding gain. Again to intensify the reliability requires extra resources (e.g., parity check, redundancy, and re-transmissions) which increases the latency [1]. Having said that the current solutions will suffer to satisfy the demand of uRLLC along with capacity and coverage, especially when many users are connected together during disaster and sports or cultural events. Moreover, operators will require additional infrastructure to facilitate such emerging applications and scenarios. However, this approach is going to be very time consuming and expensive [6]. Hence, a new flexible solution is urgently required to support uRLLC for the cellular networks.

Being motivated by the above interesting applications and scenarios, we investigated some research and current works to justify the proposed solution and their limitations. A cross-layer optimization framework has been proposed in [7] to balance up the power allocation and quality of service (QoS). It has been shown that the energy consumption decreases when matching the basic QoS requirements including latency. However, it does not discuss the issue of reducing the latency. An interface diversity scheme for uRLLC has been proposed in [8] and [9]. In this scheme, multiple different interfaces have been applied to transmit the duplicate short packets to increase the reliability and decrease the latency, but the method to extend the interfaces has not been discussed. In [10] and [11], the authors proposed a system level protocol to optimize uRLLC. Several joint scheduling schemes to support uRLLC and eMBB have been proposed in [12], [13] and [14].

Recently, the airborne networks have been introduced as key architectural enabler for beyond 5G (B5G) networks

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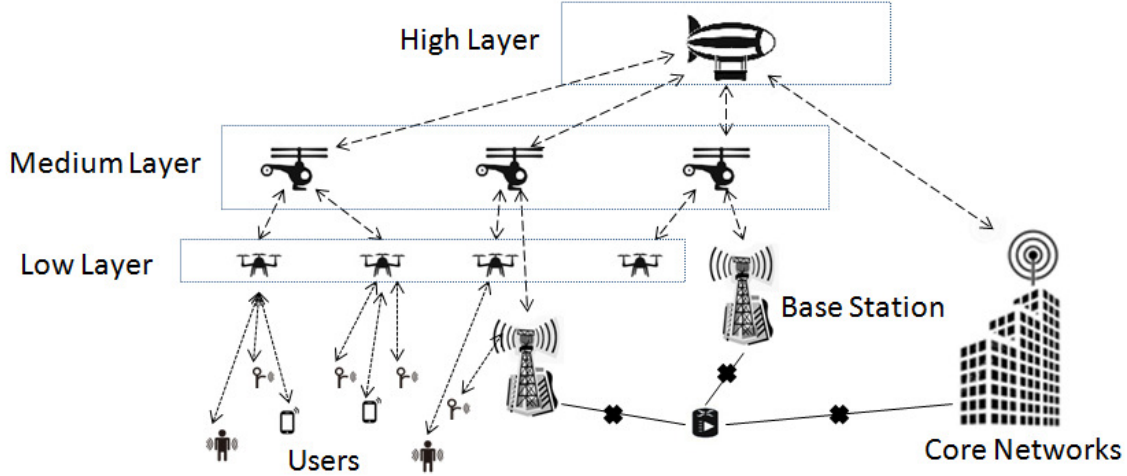


Fig. 1. An airborne network with three layers, multiple types of users connected with the core network through various flying platforms.

[15]. Many schemes have been proposed to support different applications and scenarios in future airborne networks. In [16], an optimal resource allocation scheme has been proposed to minimize the packet delay in multi-layer airborne networks. The authors in [6] have provided a delay optimized scheme using flying platforms. The reliability and flexibility of flying platforms assisted networks have been discussed in [17]. The authors in [18], [19] and [20] have proposed solutions to improve spectrum and energy efficiency of flying platform aided cellular networks. In [21], the authors have discussed the deployment of flying platforms based on the user demand, in particular, during high traffic demand scenarios.

Despite having all these current research on uRLLC and airborne networks, to the best of our knowledge, there is no key literature to support the uRLLC by the airborne networks.

### B. Our Solution and Contribution

Airborne network can be considered as a potential solution to provide capacity, coverage, reliability and low latency [15]. Such airborne networks are capable to build a flexible temporary network to increase the links and bandwidth for advanced requirements. In addition, the signal-to-noise ratio of user-to-air links is better than traditional ground links which decreases with the interference [22]. Above all, the airborne networks could be deployed in the temporary people-intensive places, such as in a stadium or during a disaster. In this way, it is possible to decrease the costly deployment of base station (BS) and associated infrastructure for temporary events. Likewise, the airborne networks could be deployed quickly to support the rescue operations during an earthquake or other natural disasters where the BS and associated infrastructure gets destroyed.

In this article, we propose a three layer airborne network with the aid of Polychromatic Sets theory (PSets). PSets is an optimization model for the analysis of complex network. Several previous works have been done on network optimization [23] and [24]. In this work, we have applied PSets on airborne

network. The PSets model is simple and efficient in contrast with the other network optimization tools.

The proposed three layers airborne network has three types of flying platforms with different performance including different roles. It is expected to provide flexible deployment and support the temporary requirements of uRLLC. In the multiple layer airborne network, the flying platforms could join in the network with different performance, so it forms a heterogeneous network. In the proposed network, it is important to measure the performance of each link and then choose the best link for end-to-end connection from lower layer to the higher layer via medium layer to offer uRLLC for the networks. Thus, we first propose the multiple property aware link selection based on PSets and then later, we propose two optimized link distribution schemes to support the uRLLC. The distributed greedy scheme focuses on the requirement of each connection in an decentralized network. On the contrary, the centralized greedy scheme focuses on the centralized network. Both schemes provide better performance than traditional schemes without considering the influence of the performance of different flying platforms.

The rest of the paper is organized as follows. In Section II, we introduce the network system model and propose the multiple properties aware airborne network description by PSets. The optimization problem is formulated in Section III and the solutions are presented in Section IV. We provide and discuss the simulation results in Section V. Finally, the conclusions are drawn in section VI.

## II. SYSTEM MODEL

Application of flying platform in current network has become more populace since recently. It would be difficult to maintain the networks with the increasing number of flying platforms. Therefore, the multi-layer architecture would be an efficient solution to deploy at no less than three layers based on their common attributes.

As shown in Fig. 1, due to the congestion or damage, the wired links cannot satisfy the requirement of uRLLC.

TABLE I  
MULTIPLE PROPERTIES OF AIRBORNE NETWORKS

| Property        | Parameter 1     | Parameter 2        | Parameter 3      | Parameter 4      |
|-----------------|-----------------|--------------------|------------------|------------------|
| Location        | $x_L$           | $y_L$              | $z_L$            | -                |
| Layer           | low layer $L_L$ | middle layer $L_M$ | high layer $L_H$ | -                |
| Idle            | busy $I_B$      | idle $I_I$         | sleep $I_S$      | -                |
| Latency         | low $Lt_L$      | medium $Lt_M$      | high $Lt_H$      | -                |
| Bandwidth       | high $B_H$      | medium $B_M$       | low $B_L$        | -                |
| Jitter          | low $J_L$       | medium $J_M$       | high $J_H$       | -                |
| Quality         | new $Q_N$       | medium $Q_M$       | old $Q_O$        | -                |
| Residual Energy | low $E_L$       | medium $E_M$       | high $E_H$       | extra-high $E_E$ |
| Protocol        | RF $P_R$        | FSO $P_F$          | mm-Wave $P_M$    | -                |

Therefore, a three layers airborne platform is deployed. The low layer (LL) comprises of low endurance flying platforms that offers connectivity to multiple users to the networks. The medium layer (ML) has medium endurance flying platforms to relay the connections between high layer (HL) and LL/BS. The HL consists of one or a few flying platforms with high endurance which can maintain in the sky for a long duration with sufficient energy and required bandwidth to offer transport network between ML and core networks (CN).

#### A. Basic Properties of Airborne Networks

In this article, we consider the deployment of various types of flying platforms in order to provide connectivity and deliver data packets in the network. For this type of complex network, we describe airborne network properties by PSets [23].

Based on PSets theory, as many as network properties could be included in the sets. As shown in Table I, the multiple properties of flying platforms in airborne network are considered such as location, layer, idle, latency, bandwidth, jitter, quality, residual energy and communication protocol. Flying platforms are associated with the layers in airborne network based on the basic QoS parameters such as their location, idle, latency, bandwidth and jitter. The performance of flying platforms decreases when they are in operation for a long time. The quality of flying platforms is considered as a comprehensive metric to measure the performance of the hardware.

Most of the flying platforms are powered by a battery and they are limited in energy. Therefore, energy efficiency has been considered as a significant performance metric in such networks. In this work, we consider the residual energy of flying platforms which is denoted by low, medium, high and extra-high as shown in Table I. Flying platforms with an extra-high residual energy represents energy harvesting enabled flying platforms with unlimited energy, such as solar battery.

It is further assumed that the flying platforms in the considered airborne networks are carrying RF/FSO/mm-Wave payload (transceivers) along with an extended battery life capabilities. In this situation, a flying platform can only connect with another flying platform which operates on the same protocol. As shown in Table I, the availability of the three protocols, RF, FSO and mm-Wave are denoted by  $P_R$ ,  $P_F$ ,  $P_M$ , respectively.

#### B. Network Description by PSets

1) *Flying platforms*: In this article, the flying platforms are categorized into three layers, as  $A_1$ ,  $A_2$  and  $A_3$ .

Set  $A$  is defined as a set of all the flying platforms in a network, which is described as  $A = \{a_1, a_2, \dots, a_i, \dots, a_p\}$ , where  $a_i$  is flying platform  $i$  in set  $A$ , which is similar to the vertices set in traditional graph, and  $p$  is the number of flying platforms. In the three layers network, flying platforms are classified into three groups, which is defined as:

$$\begin{aligned} A &= \{A_1, A_2, A_3\}, \\ A_1 &= \{a_1, \dots, a_i\}, \\ A_2 &= \{a_{i+1}, \dots, a_{i+j}\}, \\ A_3 &= \{a_{i+j+\dots+1}, \dots, a_p\}. \end{aligned} \quad (1)$$

2) *Property of flying platforms*:  $F(a)$  denotes a set of all the properties belonging to a flying platform, which is also named as an individual colour set. It is described as  $F(a) = \{f_1, f_2, \dots, f_j, \dots, f_q\}$ , where  $f$  is an individual colour and  $q$  is the number of individual colours.

For example, based on the defined properties in Table I, the set of properties  $F(a)$  is defined as  $F(a) = \{f_{L_L}, f_{L_M}, \dots, f_{P_M}\}$ . It consists of 25 parameters of the properties. However, as so far, based on the current contributions of PSets model, the 3D locations have not been considered as a property in the model.

3) *Network*: A number of flying platforms' individual colors are collected together and displayed as a matrix:

$$\begin{aligned} [A \times F(a)] &= \begin{bmatrix} f_1 & \dots & f_j & \dots & f_q \\ c_{11} & \dots & c_{1j} & \dots & c_{1q} \\ \dots & \dots & \dots & \dots & \dots \\ c_{i1} & \dots & c_{ij} & \dots & c_{iq} \\ \dots & \dots & \dots & \dots & \dots \\ c_{p1} & \dots & c_{pj} & \dots & c_{pq} \end{bmatrix} \begin{matrix} a_1 \\ \dots \\ a_i \\ \dots \\ a_p \end{matrix} \\ c_{ij} &= \begin{cases} 1, f_j \in F(a_i), \\ 0. \end{cases} \end{aligned} \quad (2)$$

If a flying platform  $a_i$  is colored  $f_j$ , then the element  $c_{ij}$  in the above matrix is set as 1, otherwise, it is 0.

### III. PROBLEM FORMULATION

In the three layers network, the connections are similar between any upper layer flying platforms and lower layer flying platforms. Therefore, we define them as a mother flying platform  $m_i$  and associated child flying platforms as  $M_L = \{m_{L1} \dots m_{Lj} \dots m_{Ln_i}\}$  where  $n_i$  denotes the number of the child flying platforms associated with a mother flying platform  $m_i$ .

Firstly, a link  $L_{ij}$  between two flying platforms following the PSets rule is defined as

$$L_{ij} \sim \{(m_i, m_{Lj}) \in [A \times A(F)]\}, \quad (3)$$

where if  $(m_i, m_{Lj}) \in [A \times A(F)]$  is true,  $L_{ij} = 1$ . Otherwise,  $L_{ij} = 0$ .  $[A \times A(F)]$  is the set of selected links by PSets model which will be introduced in section IV.

Moreover, we assume that the maximal number of links that a mother flying platform could support is  $n_{Lm_i}$ , so,

$$\sum_{j=1}^{n_i} L_{ij} \leq n_{Lm_i}. \quad (4)$$

The total bandwidth of a mother flying platform is  $b_i$ , so,

$$\sum_{j=1}^{n_i} b_{ij} \cdot L_{ij} \leq b_i, \quad (5)$$

where  $b_{ij}$  is the bandwidth of the link between flying platform  $m_i$  and  $m_{Lj}$ .

For the considered airborne network, the real-time number of routes in the three layers network is  $n_r$ . For a route  $r_k$ , it connects a HL flying platform and a LL flying platform via a ML flying platform, so the number of route hop  $h_{r_k}$  is two.

Therefore, the total latency  $T_{r_k}$  should lower than the satisfied latency  $T_s$ , as

$$\sum_{h=1}^{h_{r_k}} T_{r_k, h} \leq T_s. \quad (6)$$

Our objective is to find the lowest total latency  $T$  in a multi-hop link, as

$$\min T = \sum_{k=1}^{n_r} \sum_{h=1}^{h_{r_k}} T_{r_k, h}, \quad (7)$$

subject to

$$\begin{aligned} & \sum_{h=1}^{h_{r_k}} T_{r_k, h} \leq T_s, \\ & \sum_{j=1}^{n_i} L_{ij} \leq n_{Lm_i}, \\ & \sum_{j=1}^{n_i} b_{ij} \cdot L_{ij} \leq b_i, \\ & L_{ij} \sim \{(m_i, m_{Lj}) \in [A \times A(F)]\}. \end{aligned} \quad (8)$$

### IV. PROPOSED SCHEMES

In this section, we first propose the link discovery solution based on PSets. Then, we design two schemes for the links distribution, which are named as distributed greedy scheme and centralized greedy scheme.

#### A. Link Discovery Solution

Set  $A_k$  is defined as a set including two or more flying platforms on a route. It is a subset of set  $A$ . These flying platforms have all the selected properties  $F(A_k)$  from  $F(A)$  in the network, which is defined as:

$$\begin{cases} A_k \subset A \\ F(A_k) = \{F_1, \dots, F_m, \dots, F_n\} \subset F(A) \\ [A_k \times F(A_k)] = \begin{bmatrix} F_1 & \dots & F_m & \dots & F_n \\ 1 & \dots & 1 & \dots & 1 \\ \dots & \dots & \dots & \dots & \dots \\ 1 & \dots & 1 & \dots & 1 \\ \dots & \dots & \dots & \dots & \dots \\ 1 & \dots & 1 & \dots & 1 \end{bmatrix} \begin{matrix} A_{k1} \\ \dots \\ A_{ki} \\ \dots \\ A_{kj} \end{matrix} \end{cases} \quad (9)$$

$[A_k \times F(A_k)]$  is an all-ones matrix that flying platforms in set  $A_{ki}$  have all the selected properties  $F(A_k) = \{F_1, \dots, F_m, \dots, F_n\}$ .

The set of all the available routes are described as:

$$A(F) = \{A_{k1}, \dots, A_{ki}, \dots, A_{kj}\}. \quad (10)$$

All the link flying platforms and the corresponding properties are displayed by a matrix as:

$$\begin{aligned} & \begin{matrix} F(A_{k1}) & \dots & F(A_{kj}) & \dots & F(A_{kq}) \\ \begin{bmatrix} c_{11} & \dots & c_{1j} & \dots & c_{1q} \\ \dots & \dots & \dots & \dots & \dots \\ c_{i1} & \dots & c_{ij} & \dots & c_{iq} \\ \dots & \dots & \dots & \dots & \dots \\ c_{p1} & \dots & c_{pj} & \dots & c_{pq} \end{bmatrix} \end{matrix} \begin{matrix} a_1 \\ \dots \\ a_i \\ \dots \\ a_p \end{matrix} \\ & [A \times A(F)] = \end{aligned} \quad (11)$$

$$c_{ij} = \begin{cases} 1, a_i \in A_{kj}, \\ 0. \end{cases}$$

Specially, we divide (11) into two parts and define:

$$\begin{aligned} & \begin{matrix} \begin{bmatrix} c_{11} & \dots & c_{1j} & \dots & c_{1q} \\ \dots & \dots & \dots & \dots & \dots \\ c_{i1} & \dots & c_{ij} & \dots & c_{iq} \\ \dots & \dots & \dots & \dots & \dots \\ c_{p1} & \dots & c_{pj} & \dots & c_{pq} \end{bmatrix} \end{matrix} \begin{matrix} a_1 \\ \dots \\ a_i \\ \dots \\ a_p \end{matrix} \\ & [A \times A(F)'] = \end{aligned} \quad (12)$$

$$c_{ij} = \begin{cases} 1, a_i \in A_{kj}, \\ 0. \end{cases}$$

and

$$F(A_k)' = \{F(A_{k1}), \dots, F(A_{ki}), \dots, F(A_{kj})\}, \quad (13)$$

where  $F(A_k)'$  is a set of selected properties,  $[A \times A(F)']$  is a matrix recording the information whether the flying platform  $a_i$  belongs to set  $A_{kj}$  and has all the properties in  $F(A_{kj})$  or not.

**Algorithm 1** : PSets:  $[A_f \times F_f] \longrightarrow [A \times A(F)]$ 


---

**Input:**  $A_f, F_f, [A_f \times F_f], n_A, A_1, \dots, A_{n_A}, n_F, G_1, \dots, G_{n_F}$   
**Output:**  $[A \times A(F)], F(A_k)'$

```

1: initialization;
2: for  $m = 1 : size(G_1)$ 
3:   for  $n = 1 : size(G_2)$ 
4:     ... %total :  $n_F$ 
5:     for  $l = 1 : size(G_{n_F})$ 
6:        $[F \times F(A)] = [F_m \times A(F_m)] \wedge [F_n \times A(F_n)] \wedge \dots \wedge [F_l \times A(F_l)];$  %total :  $n_F$ 
7:       if  $F_{mnl}(a_i) \wedge F_{mnl}(a_j) \wedge \dots \wedge F_{mnl}(a_k) == 1$ 
         %total :  $n_A$ 
8:          $[A \times A(F)] \leftarrow \{a_i, a_j, \dots, a_k\};$  %total :  $n_A$ 
9:          $F(A_k)' \leftarrow F_m, F_n, \dots, F_l;$  %total :  $n_F$ 
10:      end if
11:    end for
12:  ... %total :  $n_F$ 
13: end for
14: end for

```

---

A common model is developed to acquire the set of selected links  $[A \times A(F)]$  from the set of flying platforms' unified color  $[A \times F(A)]$ . The conjunction of different flying platforms' properties  $[F \times F(A)]$  is displayed as:

$$\begin{aligned}
[F \times F(A)] &= [F_m \times A(F_m)] \wedge [F_n \times A(F_n)] \wedge \dots \wedge [F_l \times A(F_l)], \\
\exists A_{ijk} &= \{a_i, a_j, \dots, a_k\} \in [A \times A(F)], \\
F(A_{ijk}) &= \{F_m, F_n, \dots, F_l\} \in F(A_k)', \\
\forall F_{mnl}(a_i) \wedge F_{mnl}(a_j) \wedge \dots \wedge F_{mnl}(a_k) &= 1.
\end{aligned} \tag{14}$$

where  $[F_m \times A(F_m)]$  is a rank of flying platform's properties  $F_m$ ,  $A_{ijk}$  is a set of flying platforms matching the required properties,  $F(A_{ijk})$  is the set of properties which the flying platforms in  $A_{ijk}$  match and  $F_{mnl}(a_i)$  is the tag whether  $a_i$  has all the properties  $F_{mnl}$  or not.

Algorithm 1 is used to find the available paths in  $[A \times A(F)]$ . Based on this algorithm, seven parameters are required for input: a set of flying platforms  $A_f$ , a set of colors  $F_f$ , a set of flying platforms' properties  $[A_f \times F_f]$ , number of flying platform groups  $n_A$ , flying platform groups  $A_1, \dots, A_{n_A}$ , number of property groups  $n_F$  and property groups  $G_1, \dots, G_{n_F}$ . The set of selected flying platforms  $[A \times A(F)]$  and the parallel set of their matching properties  $F(A_k)'$  are output. As shown in the algorithm,  $[F \times F(A)]$  is the conjunction of different flying platforms' properties,  $[F_m \times A(F_m)]$  is a rank of flying platform's properties,  $F_m$  and  $F_{mnl}(a_i)$  are the tags whether  $a_i$  has all the properties  $F_{mnl}$  or not.

### B. Distributed Greedy Scheme

The distributed greedy algorithm has been divided into three steps, which is shown in Algorithm 2. In the two hops distributed greedy scheme, each flying platform of the lower layer only has the connection information with its mother flying platform in the upper layer. It cannot get the connection information of the whole network. Therefore, it is also difficult to update the routing discovery frequently based on the requirement.

**Algorithm 2** : Distributed Greedy Scheme

---

**Input:**  $N_H, N_M, N_L, L_H, L_M, C_{LHmax}, C_{BHmax}, C_{LMmax}, C_{BMmax}, T_{HM}, T_{ML}, T_{max}, B$   
**Output:**  $R$

```

1: Step 1: Get the list of all the available flying platforms connected to the higher layer flying platform;
2: for  $i = 1 : N_H$ 
3:   for  $j = 1 : N_M$ 
4:     if  $L_{Hij} \sim 0$ 
5:        $S_{Hi} \leftarrow L_{Hij};$ 
6:     end if
7:   end for
8: end for
9: order the flying platforms in  $S$  by increasing of distance between the flying platforms and their mother flying platform
10: Step 2: Find the flying platforms focus on the Max Bandwidth and Links;
11: Initialize:  $C_L = 0, C_B = 0$ 
12: for  $i = 1 : N_H$ 
13:   for  $j = 1 : N_M$ 
14:     if  $S_{Hij} \sim 0$  and  $C_{Li} < C_{Lmax}$  and  $C_{Bi} < C_{Bmax}$ 
15:       remove  $L_{Hij}$  from other  $S_H$ ;
16:        $C_{Li} + 1, C_{Bi} + B_j;$ 
17:     end if
18:   end for
19: end for
20: Step 3: Find the route based on the associated links;
21: for  $i = 1 : N_H$ 
22:   for  $j = 1 : N_M$ 
23:     for  $k = 1 : N_L$ 
24:       if exist  $R_{ijk}$  and  $T_{HMi} + T_{MLjk} < T_{max}$ 
25:          $R_i = (S_{Mjk}, S_{Hij});$ 
26:       end if
27:     end for
28:   end for
29: end for

```

---

Before starting the algorithm, the basic parameters have been considered as that the number of flying platforms in three layers  $N_H, N_M$  and  $N_L$ . The lists of all the available links selected by PSets route discovery algorithm are denoted by  $L_H$  and  $L_M$ . The maximum link numbers of flying platforms in high layer and medium layer are denoted by  $C_{LHmax}$  and  $C_{LMmax}$ , respectively. Variables  $C_{BHmax}$  and  $C_{BMmax}$  denote the maximum bandwidth of flying platforms in high layer and medium layer, respectively. The list of all the links' latency between high and medium layer is denoted by  $T_{HM}$  and latency list between medium and low layer is denoted by  $T_{ML}$ . The TTL (Time to Live) is denoted by  $T_{max}$ . Variable  $B$  denotes the bandwidth provided to each link. The result of the final routes is saved as set  $R$ .

1) *Step 1:* The first step is to find all the available flying platforms connected to their mother flying platform and save them as a list  $S_{Hj}$ . For the flying platforms in the medium layer, if a link between the flying platform and its mother flying platform in high layer exist in  $L_H$  based on PSets link

---

**Algorithm 3 : Centralized Greedy Scheme**


---

**Input:**  $N_H, N_M, N_L, L_H, L_M, C_{L_{Hmax}}, C_{B_{Hmax}}, C_{L_{Mmax}}, C_{B_{Mmax}}, T_{HM}, T_{ML}, T_{max}, B$

**Output:**  $R$

```

1: Initialize:  $CH_L = 0, CH_B = 0, CM_L = 0, CM_B = 0$ 
2: loop  $i = 1 : N_L$  until find the route
3:   loop  $j = 1 : N_M$  until find the route
4:   if  $L_{Mij} \sim 0$  and  $CM_{Lij} < C_{L_{Mmax}}$  and  $CM_{Bij} < C_{B_{Mmax}}$ 
5:     loop  $k = 1 : N_H$  until find the route
6:     if  $L_{Hjk} \sim 0$  and  $CH_{Ljk} < C_{L_{Hmax}}$  and  $CH_{Bjk} < C_{B_{Hmax}}$  and  $T_{HMjk} + T_{MLij} < T_{max}$ 
7:        $R_i = (L_{Mij}[1], L_{Hjk}[1]);$ 
8:        $CH_{Ljk}+ = 1, CH_{Bjk}+ = B_i, CM_{Lij}+ = 1, CM_{Bij}+ = B_i;$ 
9:     end if
10:   end loop
11: end if
12: end loop
13: end loop

```

---

discovery algorithm, the flying platform is saved in the list of its mother flying platform's available links  $S_{Hj}$ . In this step, the flying platform could have multiple available mother flying platforms, and the final mother flying platform will be decided in the next step. Then, reorder the flying platforms in the list of each mother flying platform by increasing order the distance between the flying platforms and their mother flying platform. The algorithm is also applicable to the connections between the medium layer flying platforms and the low layer flying platforms.

2) *Step 2:* The second step is to find the final connections for each mother flying platform with its child flying platforms. We consider the connections between flying platforms in the high layer and the medium layer. Firstly, initialize the counters of links as  $C_L$  and bandwidth as  $C_B$  for each mother flying platform. If a flying platform is in the list of each mother flying platform's child flying platforms  $S_{Hi}$  and the counters  $C_{Li} < C_{Lmax}$  and  $C_{Bi} < C_{Bmax}$ , the connection between the two flying platforms in two layers is selected. Then remove the same child flying platform from the lists of other mother flying platform's child flying platform  $S_H$  and update the number in the counters of link and bandwidth. The algorithm is the same as the link selection between the medium and the low layer.

3) *Step 3:* The third step is to find the route based on the associated links. For each connection requirement between the high layer and the low layer via medium layer, if a connection with two links exists, and the total latency time is lower than the TTL (Time to Live), the connection is chosen and added to the set of final routes.

### C. Centralized Greedy Scheme

As shown in Algorithm 3, in the centralized greedy algorithm, the controller has collected the connection information of all the flying platform in the network and it is able to distribute the routes for each connection.

The basic parameters of algorithm 3 are similar to the Algorithm 2. Firstly, initialize the counters of links as  $CH_L$ ,  $CM_L$  and bandwidth as  $CH_B$ ,  $CM_B$  for each mother flying platform in the high layer and the medium layer. Secondly, for each connection requirement from the source flying platform in the low layer to the destination flying platform in the high layer via the medium layer, we consider the requirement as finding the best link between the medium layer and the low layer in stage one and the best link between the high layer and the medium layer in stage two. So, if there is an available link between the flying platforms in the medium layer and the low layer, and the link and bandwidth counters of the flying platform in the medium layer are lower than the maximum links and bandwidth, check the available links between the selected flying platform in the medium layer and the destination flying platform in the high layer. Thirdly, if there is also an available link between the flying platforms in the high layer and the medium layer, the link and bandwidth counters of the flying platform in the high layer are lower than the maximum links and bandwidth, and the total latency time is lower than the TTL, choose the connection with two links as the final route for this connection requirement and add to the set of final routes. In the end, update the link and bandwidth number in the counters of the two layers.

## V. SIMULATION RESULTS AND DISCUSSIONS

The simulation is based on the scenario in Fig. 1. A three layers airborne network is deployed. The scope of flying platform deployment area is 1000m \* 1000m \* 1000m in a 3D zone. The flying platforms in three layers are deployed using Poisson distribution with the same mean parameter as half of the scope,  $x/2$ ,  $y/2$  and  $z/2$ . The location of each flying platform has been known as  $(x_L, y_L, z_L)$ . The height ranges of HL, ML and LL flying platforms are 800 ~ 1000m, 400 ~ 700m and 0 ~ 400m, respectively. The max links and bandwidth of HL flying platform are set as 30 and 300MHz, respectively.

### A. Influence of Middle Layer flying platforms Number

The flying platforms in the middle layer are seem as the relay flying platforms between the high layer and the low layer. So, we consider the influence of flying platform number in the middle layer to the average latency and overall reliability also known as unassociated ratio of network. The number of flying platforms in the high layer and the low layer are static and the number of flying platforms in the middle layer increases from 15 to 90. Other basic parameters are defined and shown in Table II. Specially, the flying platforms in middle layer are considered with different performance. These flying platforms have different random latency range, max connected links number and max bandwidth. In the simulation, we acquire the average latency and connection unassociated ratio to show the performance of the two proposed schemes.

Fig. 2 depicts the average latency vs. number of ML flying platforms. It shows that both of the two PSets based schemes decrease the latency obviously, especially when increasing the number of ML flying platforms. However, the average latency



TABLE II  
SIMULATION PARAMETERS

| Parameter                   | value                    |
|-----------------------------|--------------------------|
| location                    | $(x_L, y_L, z_L)$        |
| number: HL ML LL            | 6, [15:15:90], 90        |
| signal cover area: HL ML LL | 3000, 1000, 300          |
| scope (m): x y z            | 1000, 1000, 1000         |
| height (m): HL ML LL        | 800-1000, 400-700, 0-400 |
| max links: HL ML            | 30, [10, 5, 3]           |
| max bandwidth (MHz): HL ML  | 300, [50, 30, 20]        |
| real bandwidth (MHz):       | 5                        |

is always similar even increasing the number of ML flying platforms in the traditional shortest path scheme. In the PSets based centralized greedy scheme, the average latency is near to the shortest latency in the system (we define it as 5ms) when the number of ML flying platforms is more than 60, which is always near to 5.5ms. In the PSets based distributed greedy scheme, the average latency decrease to about 6.1ms decreasing from 7.6ms with the increasing of ML flying platforms number. The performance of the distributed scheme is poorer than the centralized scheme because each connection only has the routing information of itself and conflicts with other connections. In contrast, the flying platforms in the centralized greedy scheme have the routing information of all the flying platforms in the network and also able to select the optimized routing for the whole network.

With the limited number of ML flying platforms, the flying platforms in LL cannot always connect to HL via ML. If a LL flying platform cannot connect to HL via ML, it is unassociated. The unassociated ratio is the unassociated LL flying platforms' percentage of all the LL flying platforms. For the ultra reliability communications, the unassociated ratio should be lower than 0.01% [4] and [5]. Otherwise, it could not be able to support the uRLLC. Fig. 3 plots the unassociated ratio vs. the number of ML flying platforms. In the two types of scheme, the unassociated ratios of PSets based schemes are similar to the traditional shortest path schemes. In the centralized greedy schemes, the unassociated ratio is near to zero when the number of ML flying platforms is more than 30. In the distributed schemes, the unassociated ratio is also decreased with the increasing of ML flying platforms number. When the number of ML flying platforms is more than 45, the unassociated ratio of both distributed schemes are near to 20%. As similar with the performance of average latency, the unassociated ratio of the distributed scheme is poorer than the centralized scheme because the connections can only get the routing information of itself and have to conflict with other connections.

From the simulation result, we can see that the average latency and unassociated ratio are the lowest in the PSets based centralized greedy scheme out of all the schemes. This scheme is satisfactory to support the requirement of uRLLC. However, the unassociated ratio of PSet distributed scheme is performing marginally better than traditional distributed scheme on ultra reliability. Further optimization works should be considered

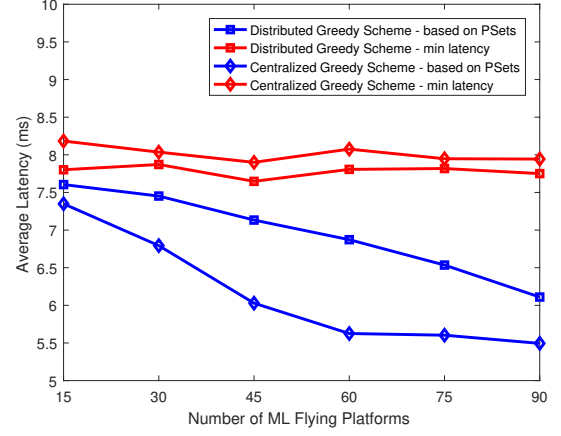


Fig. 2. Average latency vs. number of middle layer flying platforms

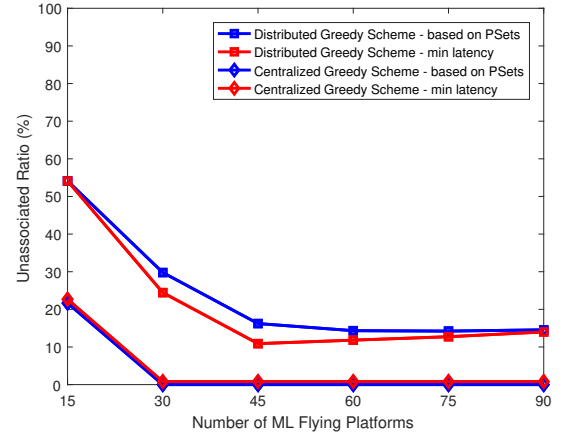


Fig. 3. Unassociated ratio vs. number of middle layer flying platforms

on decreasing the conflict of link connection.

### B. Sensitivity of User Bandwidth

Based on the simulation in previous subsection, we consider the sensitivity of different distributed bandwidth to users on the average latency and unassociated ratio. Each link in the network could support multiple users. The supported number of users depends on the bandwidth of each link and the allocated bandwidth of each user. Based on the result of average latency vs. number of ML flying platforms and unassociated ratio vs. number of ML flying platforms, the number of ML flying platforms is set as 60. It satisfies the simulation situation that both the average latency and unassociated ratio of network are low with mix number of ML flying platforms. As shown in Fig. 4, with the increasing of user's bandwidth, the average latency of traditional distributed scheme also increases. However, latency of the other schemes is not influenced. Fig. 5 demonstrate the unassociated ratio vs. the bandwidth of each user. The unassociated ratios of distributed greedy schemes increase with the increasing of user's bandwidth. The performance of distributed schemes is decreased in high bandwidth application.

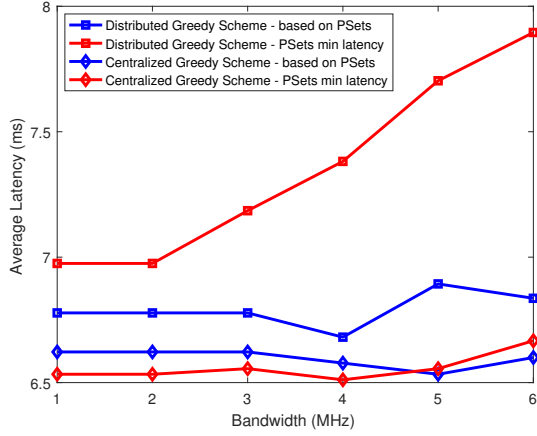


Fig. 4. Average latency vs. user bandwidth.

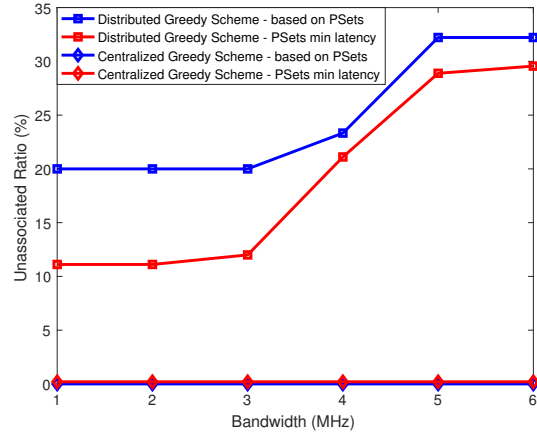


Fig. 5. Unassociated ratio vs. user bandwidth.

## VI. CONCLUSIONS

It is a potential solution to exploit airborne networks to support the uRLLC application for future networks. In this work, a PSets based optimized link selection scheme has been proposed for the uRLLC in multiple layers airborne network. Two link distribution schemes have been proposed, namely, the centralized greedy scheme and distributed greedy scheme to optimize the performance of networks. It has been shown that the PSets based scheme is able to decrease the average latency while the unassociated ratio is moderately better than the traditional schemes. It also shows that the distributed greedy scheme cannot support the ultra reliability because of the conflict on link selection. In future work, the schemes to decrease the conflict on link selection would be considered to improve the associated ratio of distributed self-organizing network along with the optimization of PSets parameters would also be proposed to support the application in the multi-layer networks.

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